THE PALEOMAGNETIC INVESTIGATION OF ANTARCTICA 1. PALEOMAGNETISM OF HUT POINT PENINSULA VOLCANIC SEQUENCE

Minoru FUNAKI

National Institute of Polar Research, 9–10, Kaga 1-chome, Itabashi-ku, Tokyo 173

Abstract: Paleomagnetic studies of 10 basaltic rock masses collected from the Hut Point Peninsula of Ross Island, Antarctica, gave the following main results. (a) The positions of virtual paleomagnetic pole (VGP) (8 normals and 2 reverses) are within a polar cap area of about 30° in radius. (b) A synthetic summary of paleomagnetic, geological and geochronological data gives a time sequence of geologic history in this area, from the younger to the older, as Twin Crater Sequence (Brunhes epoch), Half Moon Crater (Jaramillo event), Observation Hill and Cape Armitage Sequence (Matuyama epoch), and Crater Hill and Castle Rock Sequence (older than Gilsa event).

1. Introduction

The Hut Point Peninsula of Ross Island, Antarctica, about 20 km long and 2 to 4 km wide, is composed mostly of volcanic cones, lavas and ejecta, as shown in Fig. 1. Paleomagnetic studies of volcanic rocks in this area have been carried out by McMAHON and SPALL (1974a, b), KYLE and TREVES (1974) and COX (1966). McMAHON and SPALL carried out paleomagnetic studies of No. 1 (196.54 m long) and No. 2 (171.38 m long) cores obtained by the Dry Valley Drilling Project (DVDP), and reached a general conclusion that natural remanent magnetization's (NRM's) of all samples of DVDP 1 and 2 cores, except those of the layer of 1 m in thickness, are of the Matuyama reverse polarity, the average inclination of NRM being −83° (downward magnetization in southern hemisphere). KYLE and TREVES (1974) paleomagnetically examined 5 rock masses collected in the Hut Point Peninsula, *i. e.*, Twin Crater, Second Crater, Half Moon Crater, Observation Hill and lava flows 250 m north of Scott Base (see Fig. 1). As summarized in Table 1, NRM of the Observation Hill basalts is of reverse polarity but all the other four lavas have the normal polarity NRM. COX (1966) has pointed out that the Observation Hill Sequence rocks have the reverse NRM and the rocks of other sequences (Crater Hill Sequence and Half Moon Crater Sequence) have the normal NRM.

In the 1977–1978 austral summer season, rock samples were newly collected by the author at 10 sites in the Hut Point Peninsula for the purpose of paleomagnetic studies. These sampling sites are illustrated in Fig. 1, Black Knob, Scott Hut

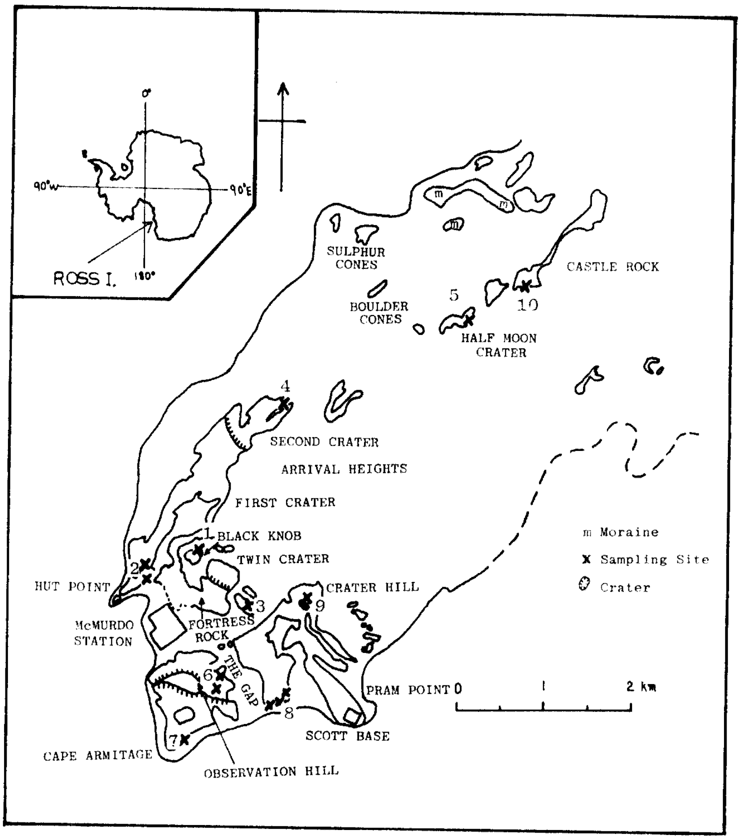

Fig. 1. Sampling sites in Hut Point Peninsula.

Peninsula, Twin Crater, Half Moon Crater, Observation Hill, Cape Armitage, lavas between Cape Armitage and Scott Base, Crater Hill and Castle Rock. The geologic time sequence of lavas and ejecta in the Hut Point Peninsula consists, from the oldest to the youngest, of a very old pile of palagonitic breccias (Castle Rock Sequence), olivine-augite basalts (Crater Hill Sequence), hornblende basalts (Half Moon Crater Sequence) and finally the youngest olivine-augite basalts (Twin Crater Sequence). According to the results of analyses of DVDP 1, 2 and 3 cores, these cores are assigned to five stages of volcanic activity sequence, namely, from the youngest to the oldest, Twin Crater, Half Moon Crater, Observation Hill, Crater Hill and Hut Point Peninsula pyroclastics (Treves and Kyle, 1973; Kyle and Treves, 1974).

As shown in Table 2, the K–Ar age of lavas of Black Knob, Half Moon Crater and Observation Hill have been determined as 0.43, 1.0 and 1.18 m.y. respectively (Kyle and Treves, 1974; Forbes *et al.*, 1974). On the other hand, the K–Ar age of a dyke intruding Castle Rock is determined as 1.1 ± 0.4 m.y. (Kyle and Treves, 1974).

Table 1. Paleomagnetic measurement of Hut Point Peninsula volcanic rocks after KYLE *and* TREVES *(1974).*

Location	N	J*	I	D	K	R	95	Polarity
North side, Twin Crater	6	6.5	−23	322	870	5.994	2.3	N (?)
South end, Second Crater	8	4.0	−80	208	537	7.987	2.4	N
South end, Half Moon Crater	1	10.2	−78	61	—	—	—	N
Observation Hill near nuclear power plant	9	2.7	84	319	89	8.910	5.5	R
Flows, 250 m north of Scott Base	9	8.7	−88	196	1836	8.996	1.2	N

* $\times 10^{-3}$ emu/cc

N: number of samples, J: intensity of magnetization, D and I: mean declination and mean inclination of remanent magnetism, respectively, K: precision constant, R: resultant vector, 95: semi-vertical angle of 95 percent confidence cone, N: normal, R: reversed.

2. Experimental Results

The declinations and inclinations for rock masses were measured by sun compass. Specimens of cylindrical shape, 1 inch in both diameter and length, were cut out from each rock mass collected from 10 sites, as summarized in Table 2. The

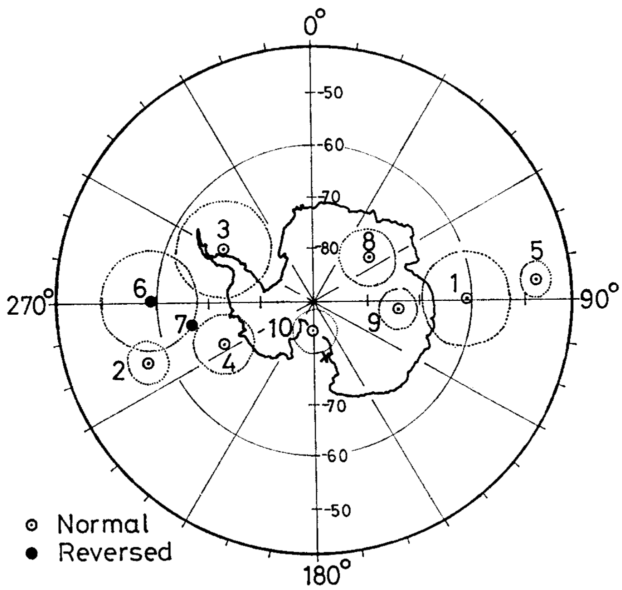

Fig. 2. V.G.P. positions at Hut Point Peninsula.
1: Black Knob, 2: Near the Scott Hut Peninsula, 3: Under the Twin Crater, 4: Second Crater, 5: Half Moon Crater, 6: Observation Hill, 7: Cape Armitage, 8: Between Cape Armitage and Scott Base, 9: Crater Hill, 10: Castle Rock, ×: Ross Island.

Table 2. Paleomagnetic measurement from Hut Point Peninsula, McMurdo Sound.

No.	Site	N	DEM	I	D	K	$\alpha 95$	Dp	Dm	LAT	LON	K-Ar age	Polarity
1	Black Knob	5	0	−73.1	303.3	48.9	11.1	17.7	19.8			0.43 ±0.1*	Normal
			150	−72.3	302.5	60.3	9.9	15.6	17.6	62.2	89.8		
2	Near the Scott Hut Peninsula	13	0	−70.7	65.4	63.3	5.3	7.9	9.1				Normal
			150	−69.9	65.9	62.9	5.3	7.8	9.1	57.1	249.8		
3	Under the Twin Crater	9	0	−84.0	103.3	37.9	8.4	16.4	16.7				Normal
			150	−84.2	110.1	33.0	9.1	17.6	17.9	70.7	312.4		
4	Second Crater	4	0	−76.9	44.1	227.0	6.1	10.6	11.4				Normal
			150	−77.1	50.3	196.3	6.6	11.4	12.3	70.8	244.5		
5	Half Moon Crater	6	0	−59.8	289.3	122.2	6.1	6.9	9.2			1.0 ±0.2*	Normal
			150	−59.6	290.6	217.9	4.5	5.1	6.8	47.7	86.6		
6	Observation Hill	7	0	76.0	269.3	57.3	8.0	13.7	14.8			1.18 ±0.03**	Reversed
			150	73.4	264.0	31.2	11.0	17.6	19.6	−58.2	91.4		
7	Cape Armitage	1	0	77.3	242.9								Reversed
			150	76.2	244.9					−66.5	77.6		
8	Between Cape Armitage and Scott Base	5	0	−83.0	303.4	171.8	5.9	11.2	11.5				Normal
			150	−83.1	298.7	169.1	5.9	11.3	11.6	76.9	52.2		
9	Crater Hill	10	0	−77.9	320.4	142.7	4.1	7.2	7.6				Normal
			150	−78.0	319.1	139.8	4.1	7.3	7.7	74.2	97.1		
10	Castle Rock	3	0	−82.3	4.4	364.9	6.5	12.3	12.6				Normal
			150	−80.3	5.1	924.3	4.1	7.5	7.8	83.2	180.7		

N: sample number, DEM: AF-demagnetization, I: inclination, D: declination, K: estimate of precision, $\alpha 95$: semi-angle of the cone of confidence at the 95% probability level, Dp and Dm: the 95% probability errors in the estimated paleomagnetic pole, LAT: paleolatitude, LON: paleolongitude, * ARMSTRONG (KYLE *et al.*, 1974), ** FORBES *et al.* (1974).

intensity and direction of NRM of original specimens and NRM after the AF-demagnetization were measured by a spinner magnetometer. Table 2 shows the number of examined specimens (N) collected at the same site, the mean inclination (I) and declination (D) of NRM before the AF-demagnetization (DEM=0) and after the AF-demagnetizing up to 150 Oe peak (DEM=150) for the ten groups. As seen in the table, the direction of NRM after AF-demagnetizing up to 150 Oe peak is practically the same as that before the AF-demagnetization, so that NRM of all basaltic rocks in the Hut Point Peninsula can be considered sufficiently stable. In Table 2, the estimate of precision (K), the semi-angle of the core of confidence of 95% probability (α95), the paleolatitude (LAT) and paleolongitude (LON) of the virtual paleomagnetic pole (VGP) and 95% probability errors in the estimated paleomagnetic pole (Dp, Dm) are given for each group of the examined basaltic rocks.

The original NRM intensities of these basaltic rocks range from 10.1×10^{-3} emu/cc to 0.3×10^{-3} emu/cc, the mean value being 3.0×10^{-3} emu/cc, but the NRM intensities after AF-demagnetizing to 150 Oe peak take various values. However, since the stability of NRM direction is sufficiently high, the NRM direction data of all the basaltic rock groups will be reliable as paleomagnetic data. The positions of VGP of the ten rock groups are plotted in Fig. 2, where NRM's of (6) Observation Hill and (7) Cape Armitage basalts are of the reverse polarity, whereas those of the other eight groups are of the normal polarity.

3. Paleomagnetic Discussion

The new paleomagnetic data summarized in Table 2 will be first compared with the previous data given in Table 1, where the lava flow 250 m north of Scott Base can be considered practically the same lava as (8) lava between Cape Armitage and Scott Base and (9) lava at Crater Hill given in Table 2. In both groups of paleomagnetic data, the paleomagnetic polarity is normal for (3) under Twin Crater, (4) Half Moon Crater and (9) Crater Hill basalts and is reversed for (6) Observation Hill basalt. A difference in angle of the NRM direction between (8) and (9) is only 6° while a difference in angle of the NRM direction of the lava flow 250 m north of Scott Base in Table 1 from that of (8) is also only 8°. Since these deviation angles are of the same order of magnitude as the α95 values of the respective rock specimens, it may be concluded that the mutual agreement of paleomagnetic direction among the three sample groups is reasonably good. The difference in angle (Θ) between the paleomagnetic directions of Table 1 and Table 2 is 11° for the Observation Hill basalt, but Θ value amounts to 62° and 39° for the Twin Crater basalt and the Half Moon Crater basalt respectively. Taking into account the α95 values of the respective rocks, the paleomagnetic direction of (6) Observation Hill basalt given in the two tables are in reasonably good agreement with each other, but Θ values for the Twin Crater and Half Moon Crater basalts considerably exceed their α95 values. Since N=1 for the Half Moon Crater basalt in Table 1, the statistical reliance of the paleomagnetic direction may be considered poor, for this case. However, the discrepancy between the paleomagnetic directions for the Twin Crater basalt, represented by $\Theta=62°$, is statistically significant. This discrepancy may be due to the difference of the sampling sites. As will be discussed later, the age of the Twin Crater lavas is considered not very much older than that of the Black Knob lava (0.43±0.1 m.y.) and is younger than the Half Moon Crater lavas (1.0±0.2 m.y.) judging the geological layered structure. From this viewpoint of lava flow sequence, it seems likely that the I value of $-23°$ for the Twin Crater lava in Table 1 is too much anomalous, and it probably presents a certain local anomaly.

The positions of VGP of 10 groups of lavas, plotted in Fig. 2, are confined to the polar cap area within 45° in colatitude, and those of 9 groups (excluding (4) Half Moon Crater lavas) are distributed within a polar cap area of 32° in colatitude of the outer boundary. A marked characteristic of the distribution of VGP in Fig. 2 will be presented by an elongation of the distribution area along the 90°–270° meridian line.

The historical sequences of lava flow ejections in this area and the geomagnetic pole movement will be clarified to a certain extent by synthetically referring to the field evidence of geology, geochronological data of lavas and the present paleomagnetic results. The Black Knob lava, which is 0.43 m.y. in K–Ar age and normal in the magnetic polarization, is probably the youngest volcanic rock in the Hut Point Peninsula (WELLMAN, 1964). Lavas of Black Knob, southwest of Black Knob, near Scott Hut Peninsula, under Twin Crater and Second Crater belong to the Twin Crater Sequence, and all these lavas are normally magnetized. The K–Ar age of lava in the southwest of Black Knob has been determined as 0.58±0.06 m.y. (KYLE and TREVES, 1974). The lava near the Scott Hut Peninsula is under the lava in the southwest of Black Knob, so that the age of the Scott Hut Peninsula lava must be older than 0.58 m.y. The lavas under Twin Crater and of Second Crater are older than the Black Knob lava and are normally magnetized, hence these two lavas are presumed to have flowed out during a period from 0.69 to 0.43 m.y. ago (see Fig. 3). Since the Half Moon Crater lava is 1.0±0.2 m.y. in the K–Ar age and normally magnetized, it is most likely that the Half Moon Crater volcanic activity took place during the Jaramillo event, *i. e.*, 0.89 to 0.95 m.y. in age (COX, 1966), as illustrated in Fig. 3. Both Observation Hill lava and Cape Armitage lava gave the reverse magnetic polarity. As the K–Ar age of the Observation Hill lava is 1.18±0.03 m.y., its magnetic polarity is in accordance with the world standard paleomagnetic polarity data (Fig. 3). Since the trachyte of Observation Hill intrudes the Cape Armitage lava at a locality between Observation Hill and Cape Armitage, the Cape Armitage, the Cape Armitage lava should be older than the Observation Hill lava. However, since the VGP of the former is close to that of the latter (Fig. 2), the age of the Cape Armitage lava would be only a little older than that of the Observation Hill lava (Fig. 3). The Castle Rock basaltic breccia consists of a number of fragments of large grain size (5 to 20 cm diameter) and the palagonitic matrix including small fragments of basalt less than 5 mm in diameter. The matrix of the Castle Rock breccia is systematically magnetized into the normal direction (Table 2), but the directions of NRM of the large basaltic conglomerates are widely dispersed. The Castle Rock

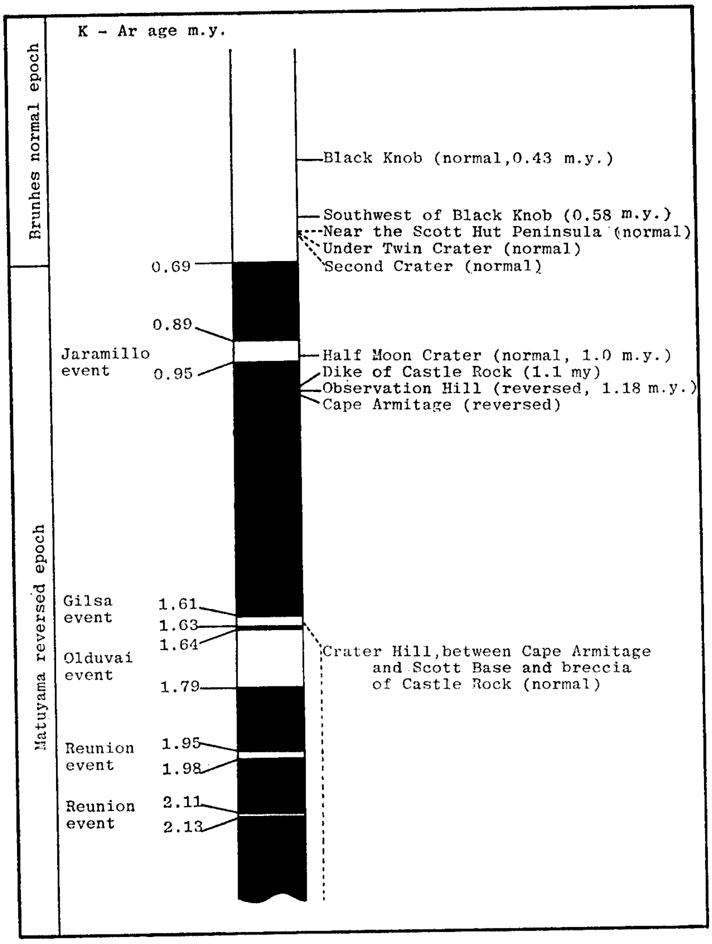

Fig. 3. Lava flow sequence of Hut Point Peninsula.

breccia is considered as a subglacial or submarine deposit (KYLE and TREVES, 1974), and the K–Ar age of an olivine-augite dyke intruding this breccia layer is determined to be 1.12 m.y. (KYLE and TREVES, 1974). Then, the most plausible interpretation of the paleomagnetic result of the Castle Rock will be such that this breccia is a product of the deposition of basaltic materials during a geomagnetic normal polarity epoch before 1.12 m.y., resulting thus in an acquisition of depositional remanent magnetization (DRM) of the matrix and random orientation of large size conglomerates which may have been unable to follow the geomagnetic force. It is most likely, from this viewpoint, that the formation of the Castle Rock breccia took place before the Gilsa event (1.61 to 1.63 m.y. in age). Crater Hill lavas are normally magnetized at the top of Crater Hill and between Cape Armitage and Scott Base. Since these lavas are overlain by the Observation Hill trachyte, they must be older than 1.18 m.y. in age. Then, the age of formation of the Crater Hill lavas is presumed to be older than the Gilsa event for the same reason as applied to the Castle Rock breccia.

4. Concluding Remarks

Results of the present paleomagnetic studies of 9 basaltic lavas and one basaltic breccia in the Hut Point Peninsula are summarized in the VGP distribution in Fig. 2 and in the geologic history diagram with the geomagnetic polarity scale in Fig. 3. The ellipse confidence for VGP in Fig. 2 suggests that the positions of VGP are confined to the polar cap area within 45° colatitude, and those of 9 groups (excluding Half Moon Crater lavas) are distributed within a polar cap area of 32° in colatitude of the outer boundary along the 90°–270° meridean line. A synthetic summary of paleomagnetic, geological and geochronological data gives a time sequence of geologic history in the Hut Point Peninsula, from the younger to the older, as Twin Crater Sequence (Brunhes Epoch), Half Moon Crater (Jaramillo event), Observation Hill and Cape Armitage Sequence (Matuyama epoch) and Crater Hill and Castle Rock Sequence (older than Gilsa event).

Acknowledgments

The author thanks Prof. T. NAGATA, Director of National Institute of Polar Research, for many useful suggestions. This research was done in the 1977–1978 austral summer season with the support from the U. S. National Science Foundation.

References

COX, A. V. (1966): Paleomagnetic research on volcanic rocks of McMurdo Sound. Antarct. J. U. S., **1** (4), 136.

FORBES, R. B., TURNER, D. T. and CARDEN, J. R. (1974): Age of trachyte from Ross Island, Antarctica. Geology, **2**, 297.

KYLE, P. R. (1974): Petrology and mineralogy of DVDP 1 and 2 core samples. DVDP Bull., **4**, 33 (abstr. only).

KYLE, P. R. and TREVES, S. B. (1973): Review of the Geology of Hut Point Peninsula, Ross Island, Antarctica. DVDP Bull., **2**, 1–10.

KYLE, P. R. and TREVES, S. B. (1974): Geology of Hut Point Peninsula, Ross Island. Antarct. J. U. S., **9** (5), 232–234.

MCMAHON, B. E. and SPALL, H. (1974a): Paleomagnetic data from unit 13, DVDP hole 2, Ross Island. Antarct. J. U. S., **9** (5), 229–232.

MCMAHON, B. E. and SPALL, H. (1974b): Results of paleomagnetic investigation of selected cores recovered by Dry Valley Drilling Project. DVDP Bull., **4**, 37–38.

TREVES, S. B. and KYLE, P. R. (1973): Geology of DVDP 1 and 2, Hut Point Peninsula, Ross Island Antarctica. DVDP Bull., **2**, 11–82.

WELLMAN, H. W. (1964): Later geological history of Hut Point Peninsula, Antarctica. Trans. R. Soc. N. Z., **2**, 149–154.

(Received April 26, 1979; Revised manuscript received June 4, 1979)